

Climate change as an entrepreneurial challenge

Jonathan Koomey

Research Fellow, Steyer-Taylor Center for Energy
Policy and Finance, Stanford University

jgkoomey@stanford.edu

<http://www.koomey.com>

Lawrence Berkeley National Laboratory

October 21, 2014

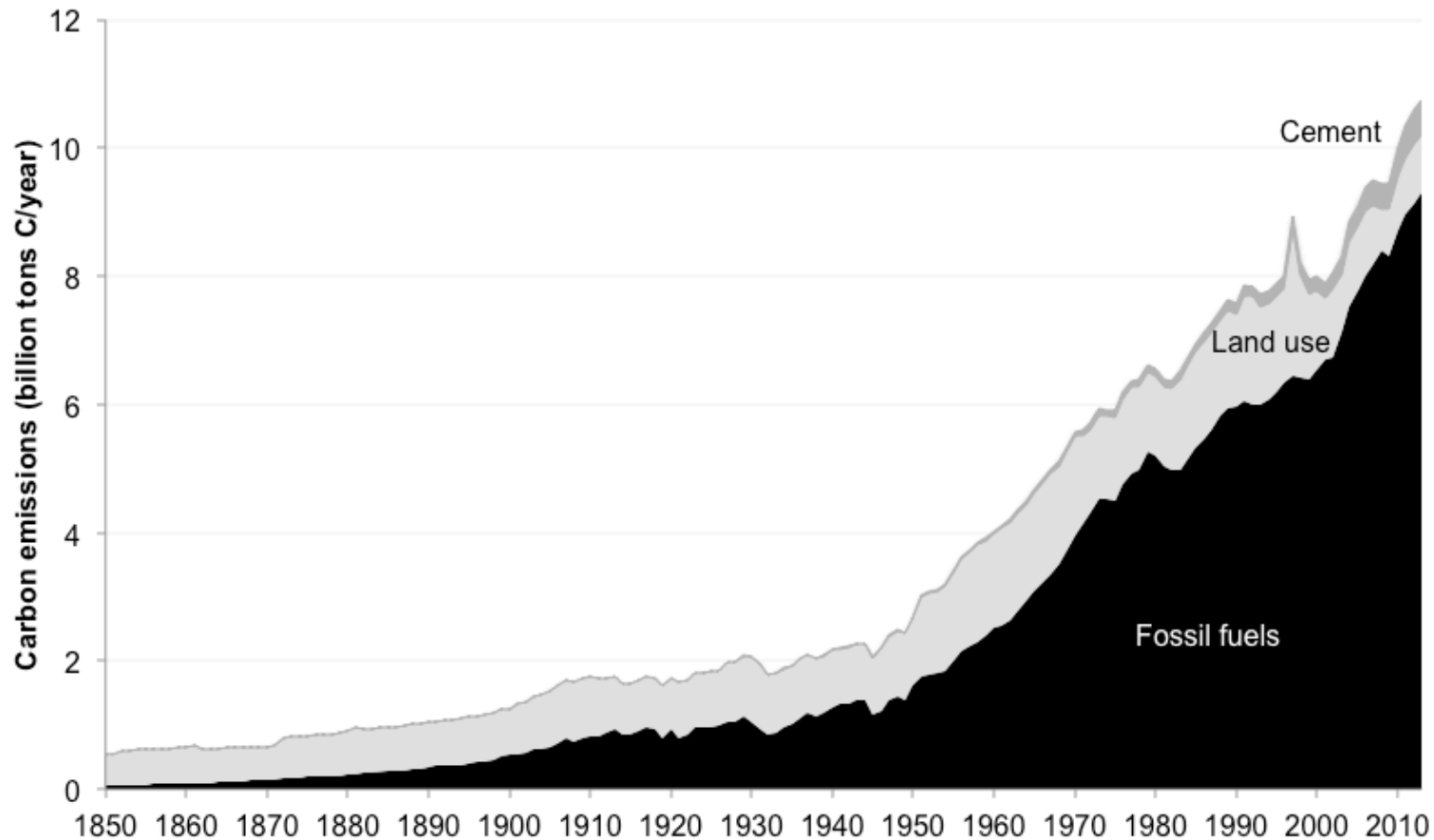
The world is warming and humans are responsible

“A strong, credible body of scientific evidence shows that climate change is occurring, is caused largely by human activities, and poses significant risks for a broad range of human and natural systems. . . .

Some scientific conclusions or theories have been so thoroughly examined and tested, and supported by so many independent observations and results, that their likelihood of subsequently being found to be wrong is vanishingly small. Such conclusions and theories are then regarded as **settled facts**. This is the case for the conclusions that **the Earth system is warming and that much of this warming is very likely due to human activities.**”

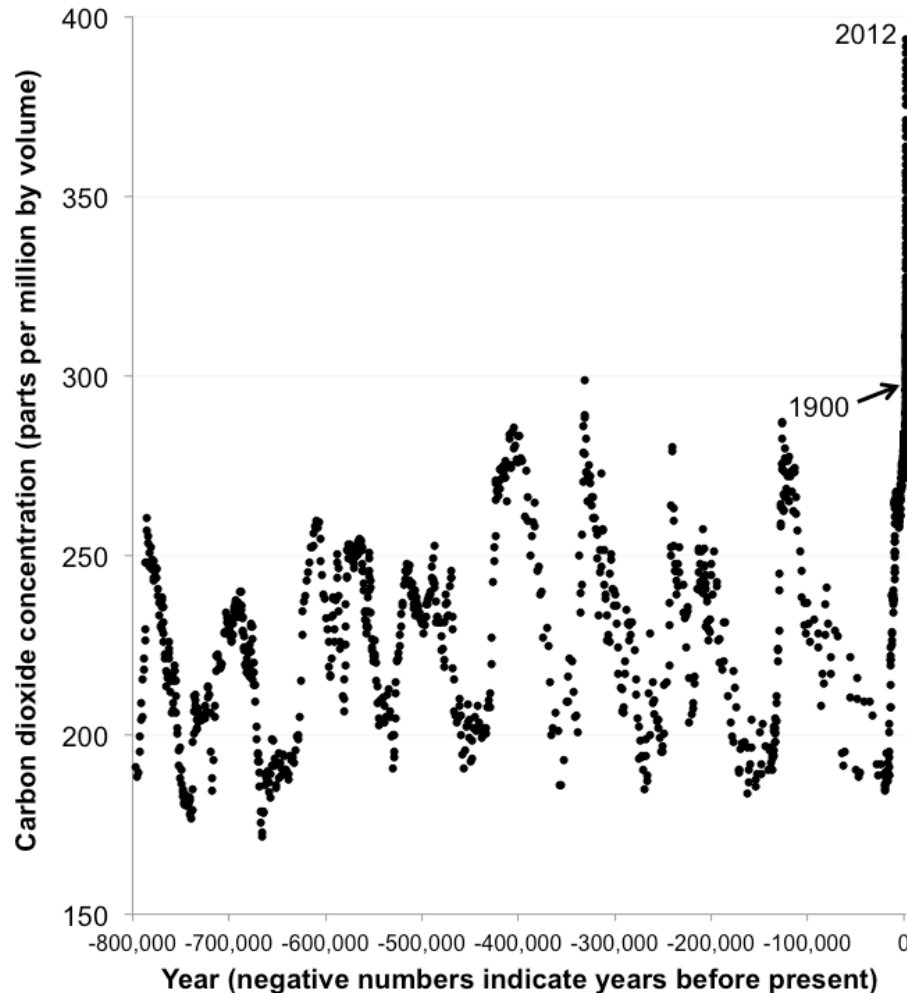
US National Academy of Sciences. 2010. *Advancing the Science of Climate Change*

Historical global C emissions



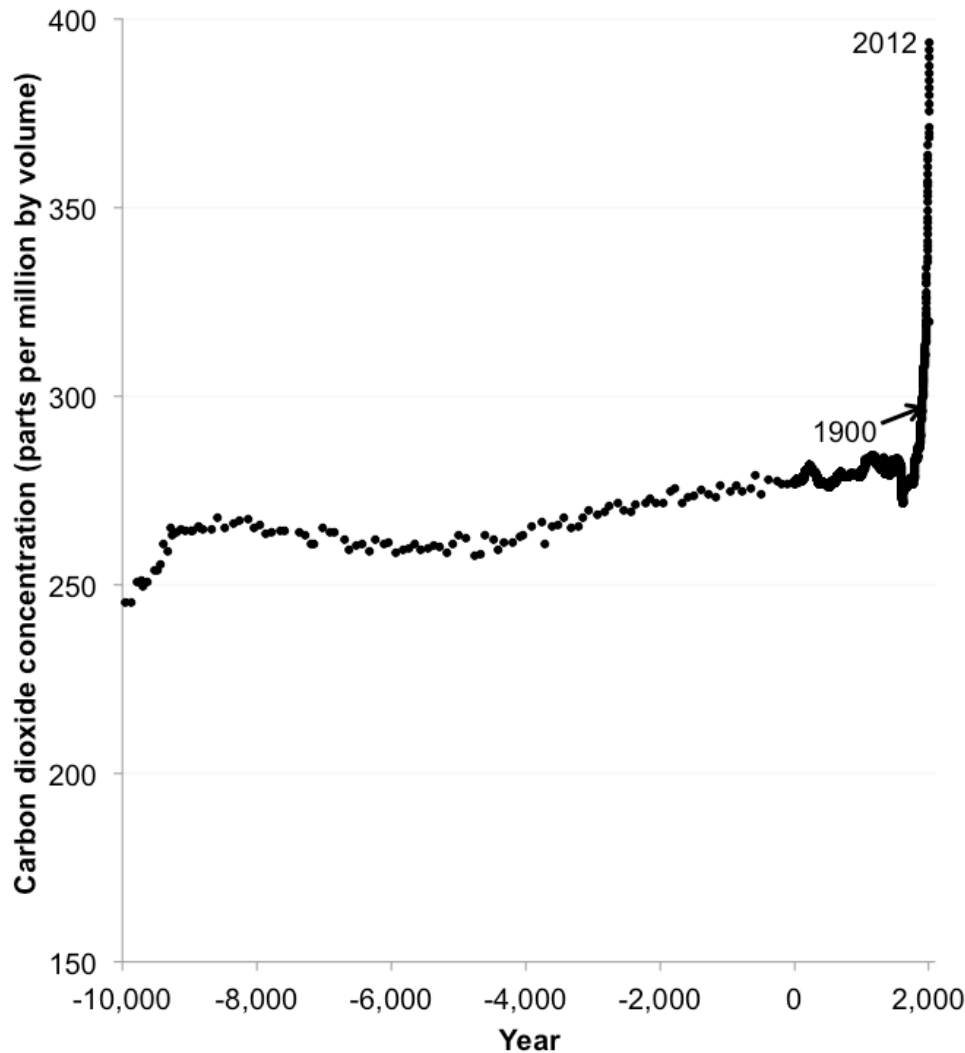
Source: Carbon Dioxide Information Analysis Center (CDIAC)

Big jump in CO₂ concentrations from fossil fuels and land use changes



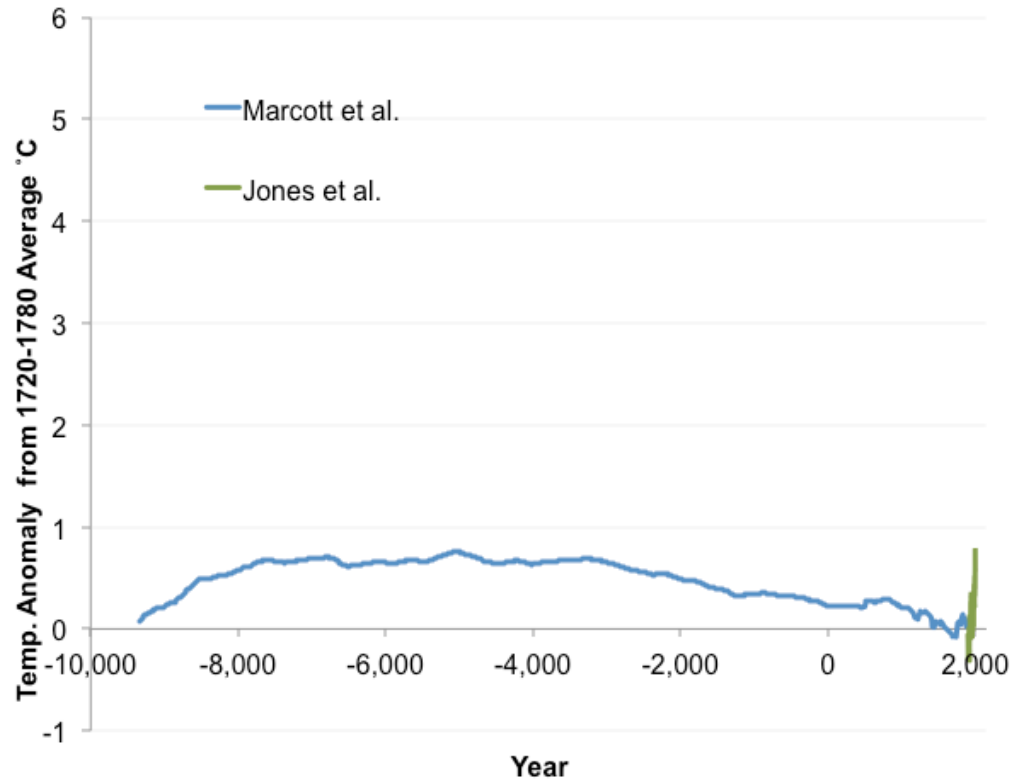
Sources: Vostok and Lawdome ice core data, plus measured concentrations from the Carbon Dioxide Information Analysis Center, plotted in *Cold Cash, Cool Climate*

A closer look at the last 12,000 years



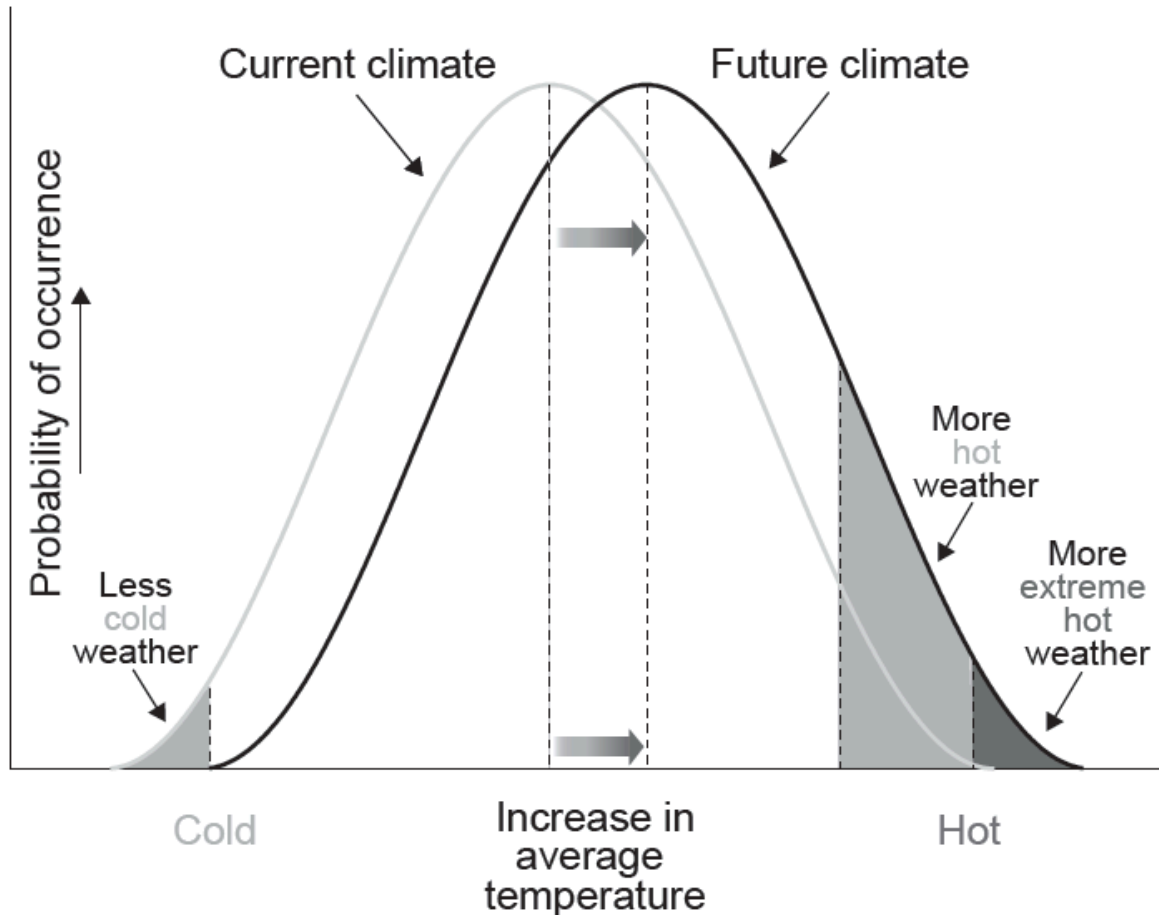
Sources: Vostok and Lawdome ice core data, plus measured concentrations from the Carbon Dioxide Information Analysis Center, plotted in *Cold Cash, Cool Climate*

Global surface temperatures have risen in the last century



Source: Marcott et al. (2013) and Jones et al. (2013)

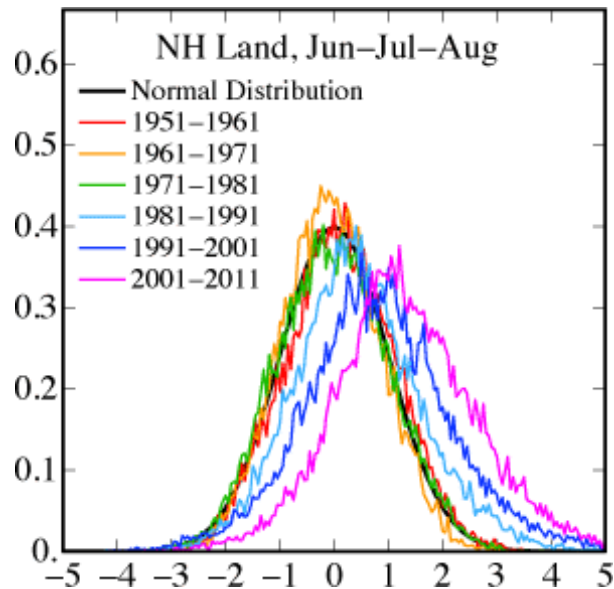
Increasing temperatures “load the dice”



Source: Adapted from a graph made originally by the University of Arizona, Southwest Climate Change Network

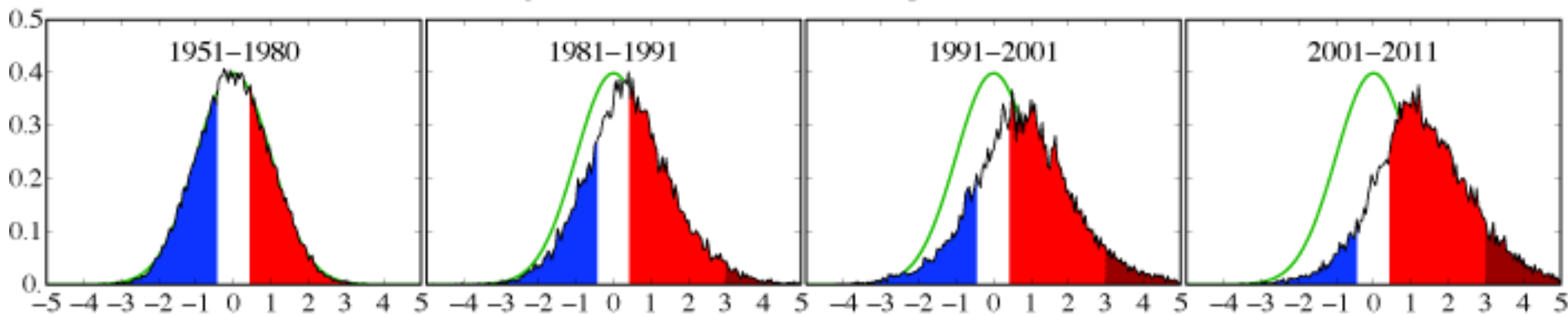
Copyright Jonathan Koomey 2014

What the data show

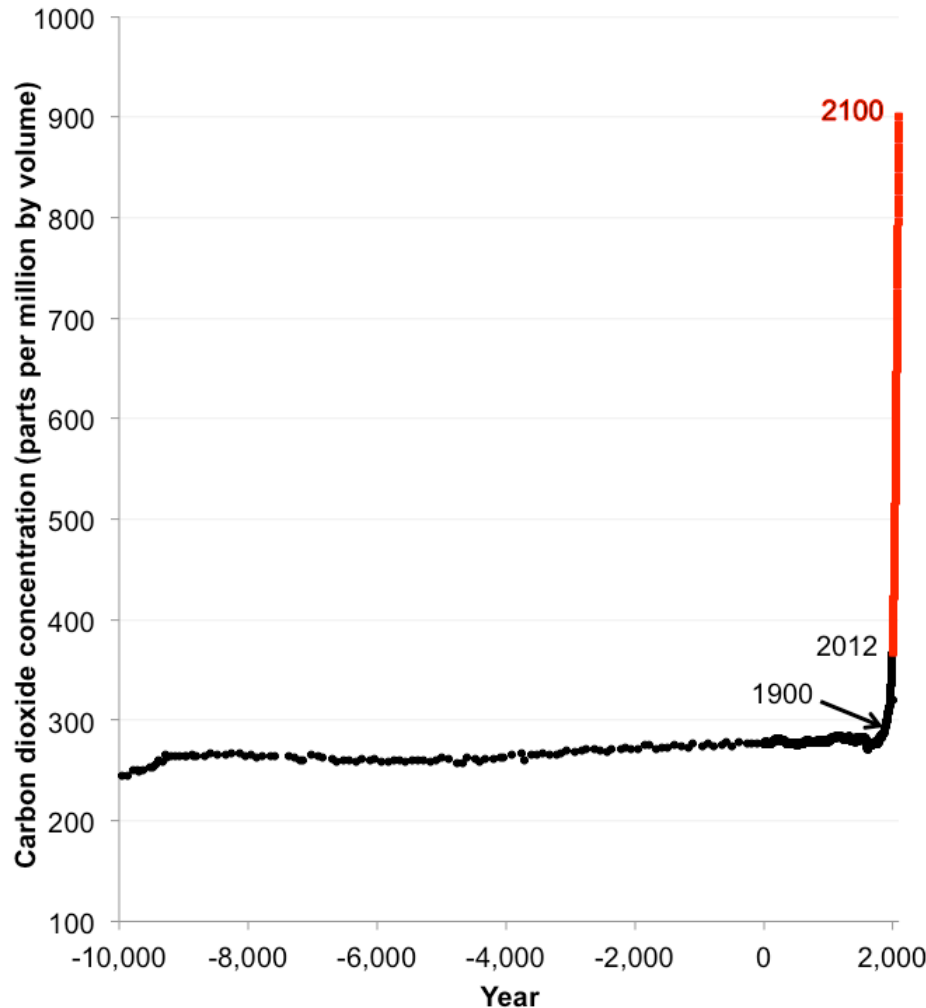


Source: *The New Climate Dice: Public Perception of Climate Change*. James Hansen, Makiko Sato, and Reto Ruedy. August 2012.
http://www.giss.nasa.gov/research/briefs/hansen_17/. Data are for Northern Hemisphere. X-axes in graphs below are in standard deviations, not C degrees.

Shifting Distribution of Summer Temperature Anomalies

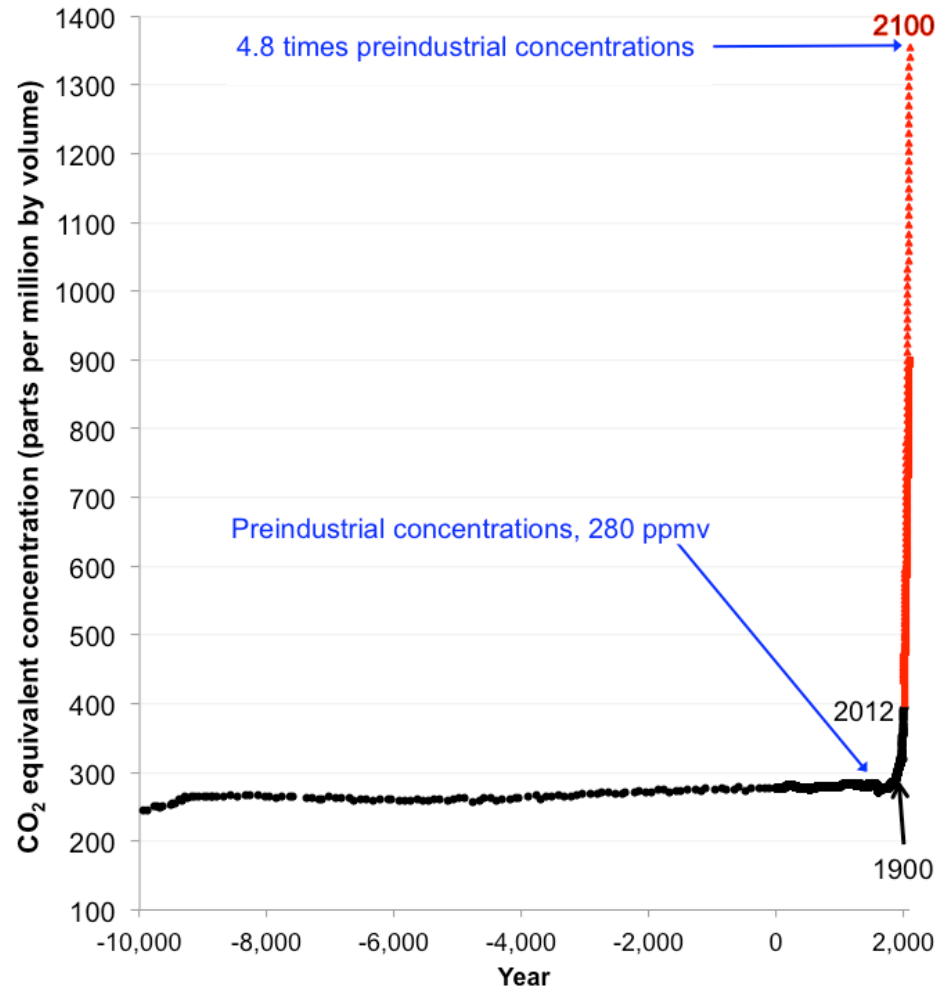


No-policy case carbon dioxide concentrations to 2100



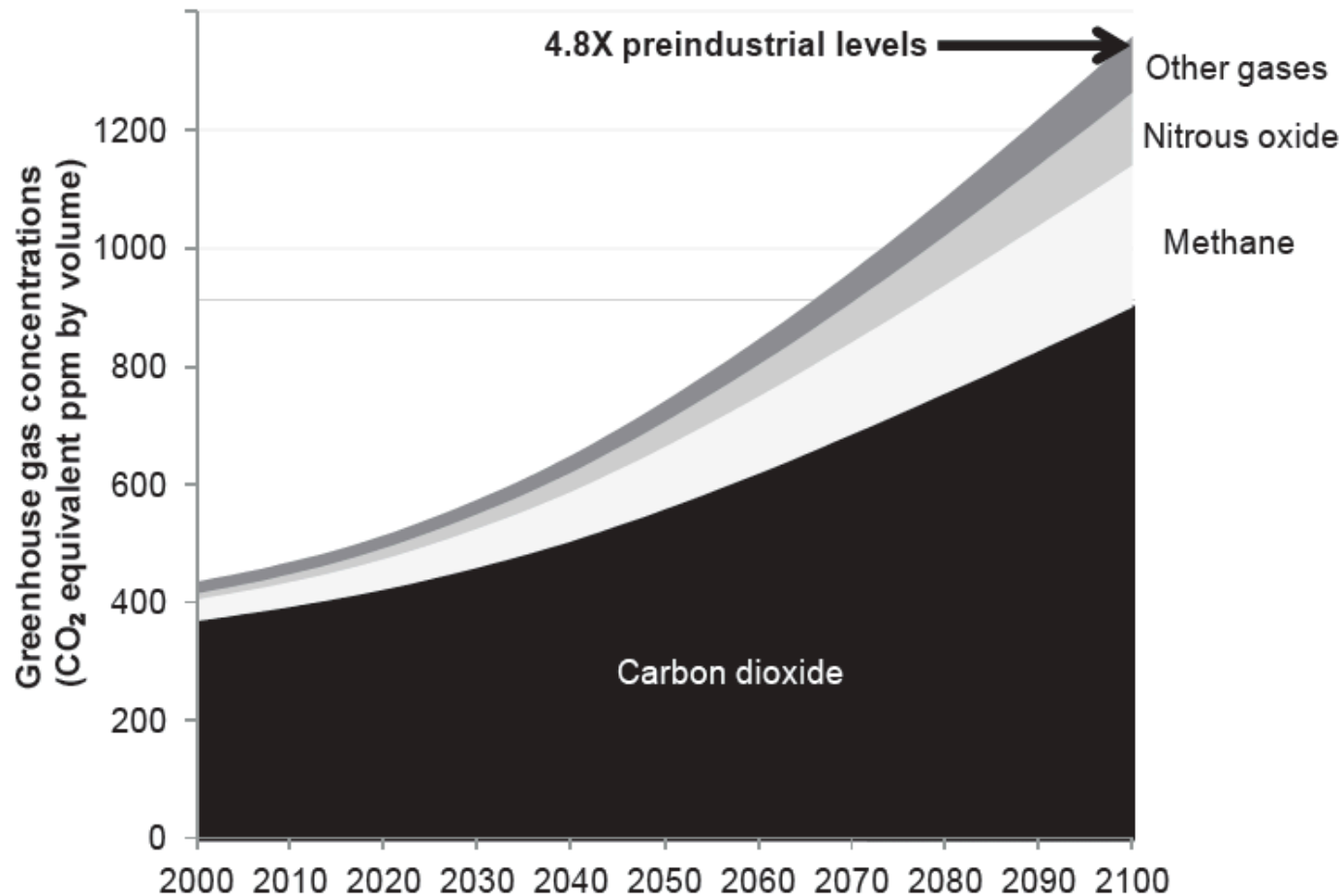
Source: Sokolov et al. 2009 for projected concentrations and ice core and directly measured data for historical numbers.

No-policy case greenhouse gas concentrations to 2100 (all gases)



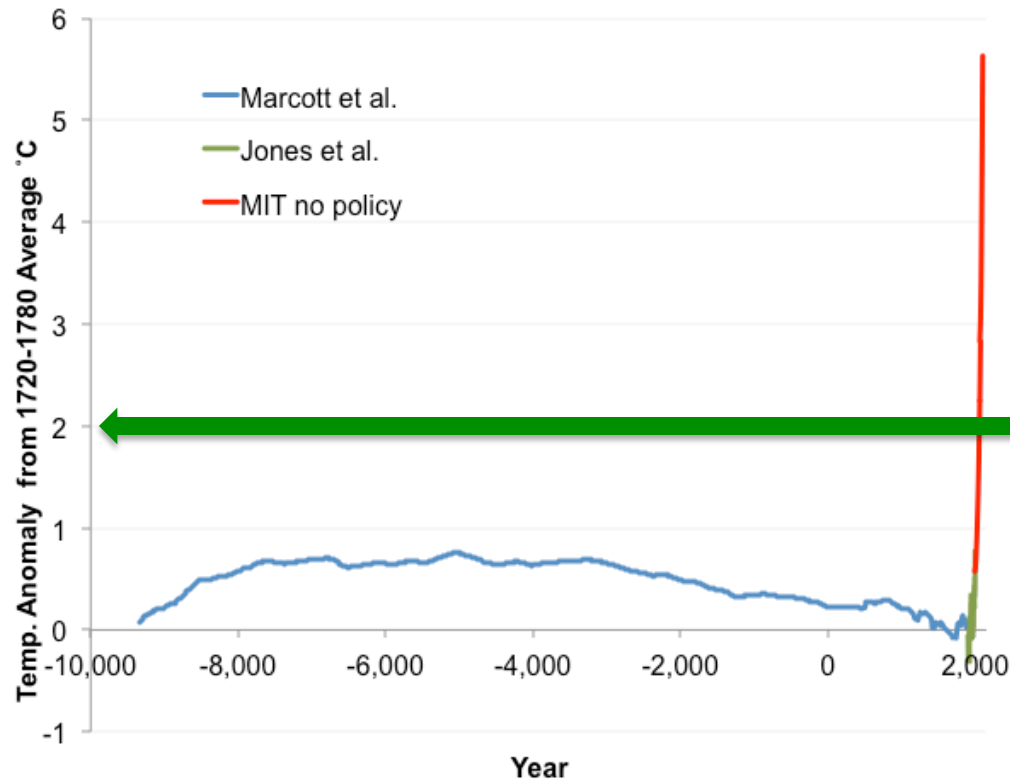
Source: Sokolov et al. 2009 for projected concentrations and ice core and directly measured data for historical numbers.

No-policy case greenhouse gas concentrations to 2100



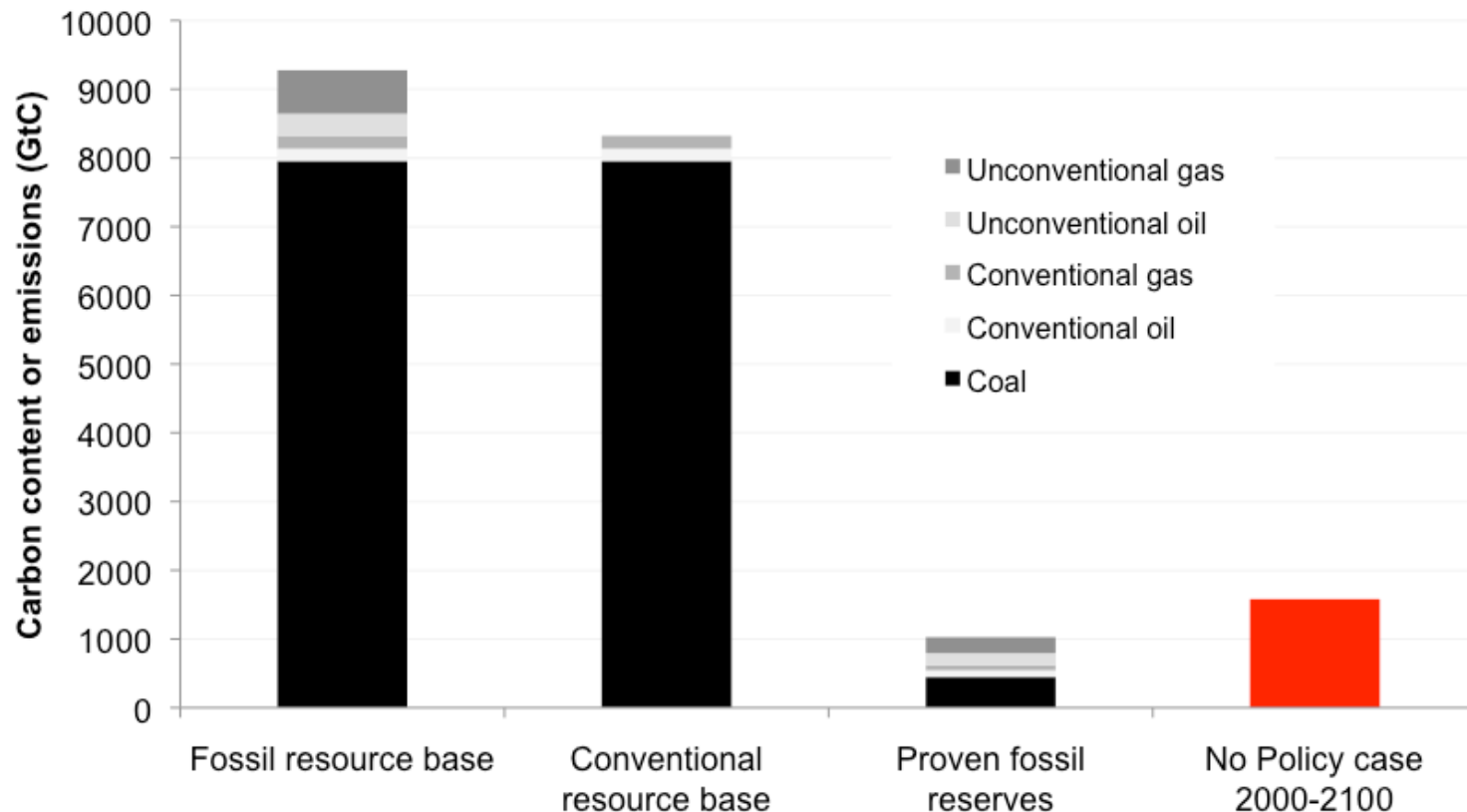
Source: Sokolov et al. 2009, plotted in *Cold Cash, Cool Climate*

Current trends = 5 C degrees by 2100, with no end in sight



Historical data from Marcott et al. (2013) and Jones et al. (2013), with MIT projection taken from Sokolov et al. 2009. MIT climate sensitivity is 2.9 degrees C, but warming by 2100 doesn't reflect the full warming impact because full equilibration takes centuries.

Fossil fuel scarcity will not constrain carbon emissions



Source: Lower bound resource estimates from the IIASA Global Energy Assessment 2012 + Sokolov et al. 2009 (fossil emissions only).

What can we do?

Calvin and Hobbes

by Bill Watterson



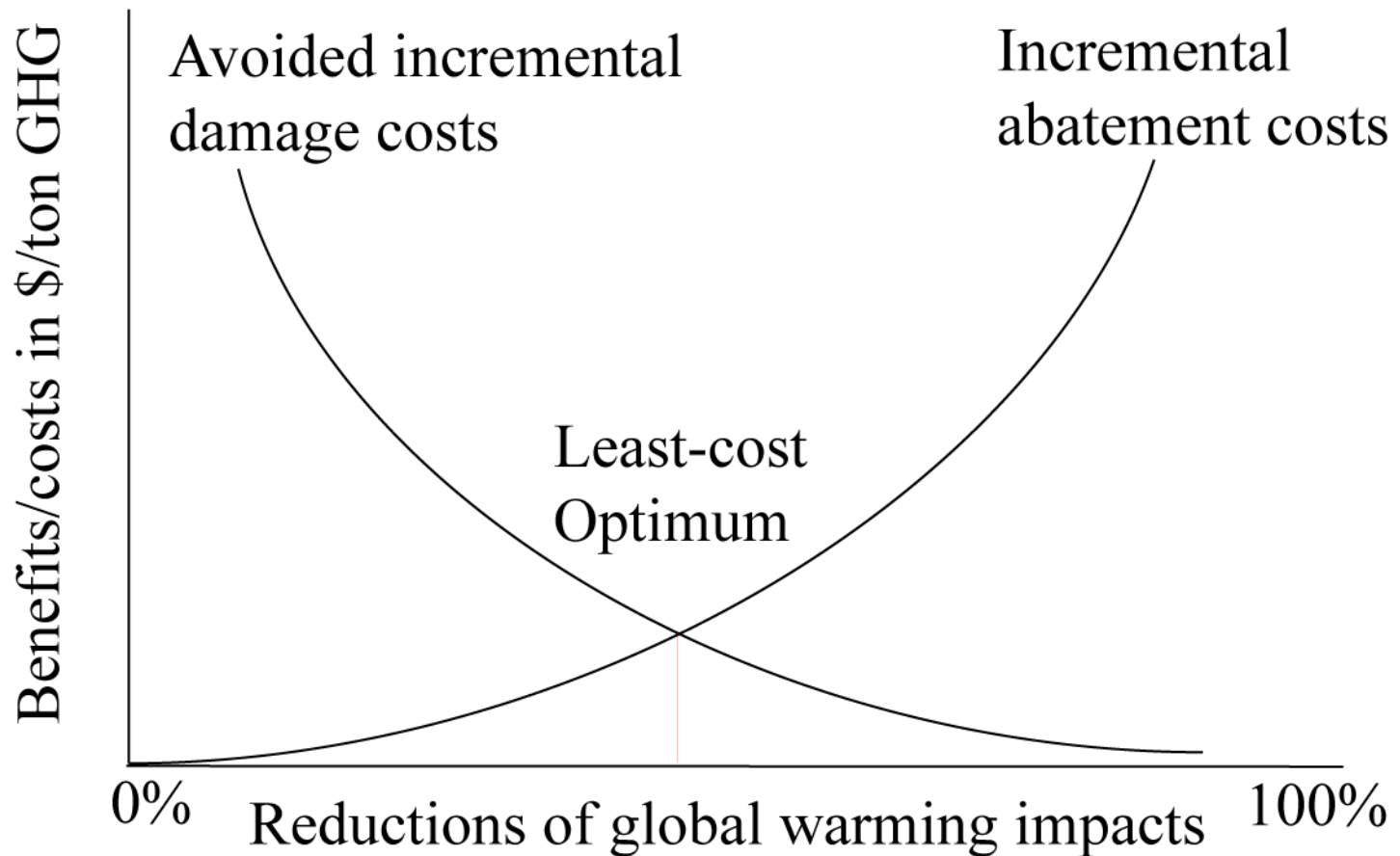
Our options

- Adapt—modify human systems to make them more flexible and resilient
- Suffer—accept what comes (but what comes is likely to be costly in lives, ecosystem damage, and economic disruption)
- Mitigate—reduce emissions

Questions about mitigation options

- How much carbon will they save?
- How much will they cost?
- Are they feasible
 - technically? (science and technology)
 - logistically? (implementation and policy)
 - politically? (social will and equity)

Cost-benefit analysis: the standard approach



The forecasting quandary

- Economics \neq physics: we need to act, but it's impossible to calculate costs and benefits in an accurate way
- Implication: the conventional model of full benefit-cost analysis before acting is not adequate to address this problem

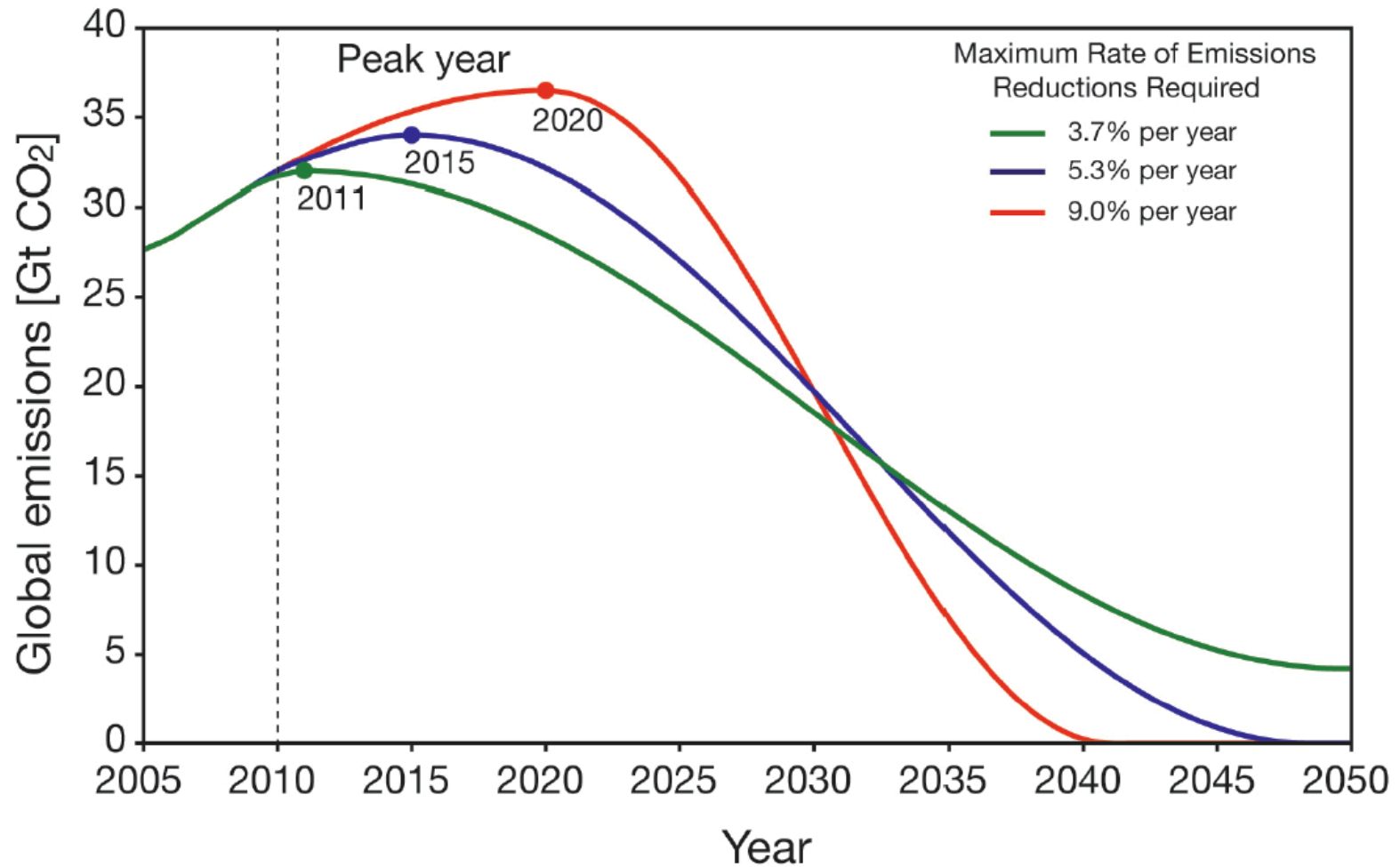
An evolutionary, path-dependent view

- There is no “optimal path”, but there are many possible alternative paths
 - We can’t plan or know everything about the path ahead but the warming limit defines the broad outlines of success
- Our choices now affect our options later
- Need to
 - invest in a broad portfolio of options
 - fail fast
 - modify plans dynamically
 - learn as fast as we can

An alternative approach

- Define a warming limit (e.g. 2 C degrees above preindustrial levels)
- Determine the total greenhouse gases we can then emit to stay under that limit
- Define pathways that meet that constraint
- Assess what we'd need to do achieve that pathway (# of power plants, rate of improvement in energy efficiency, etc)
- Try options, fail fast, alter course as needed

There's no time to waste

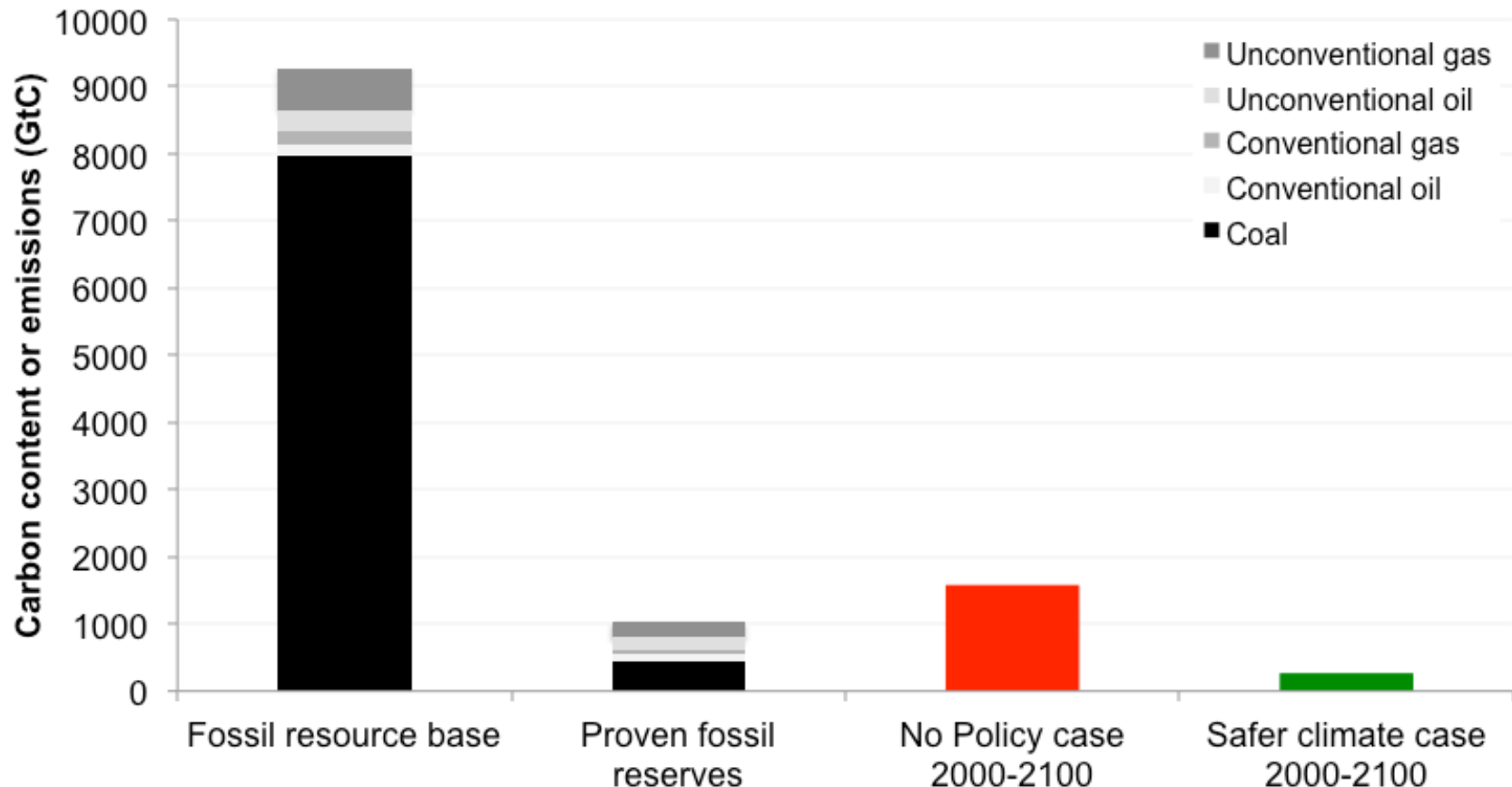


Source: The Copenhagen Diagnosis, 2009

Working toward the limit

- Like strategic planning, not forecasting
- e.g., to meet some fraction of the target
 - how many emission-free power plants would we have to build and how much capital would that require?
 - how fast would efficiency need to improve given expected rates of economic growth?
 - what institutional changes would be needed to accelerate the rate of implementation?
- A way to organize our thinking about solutions to the problem

Meeting constraints of the safer climate case won't be easy



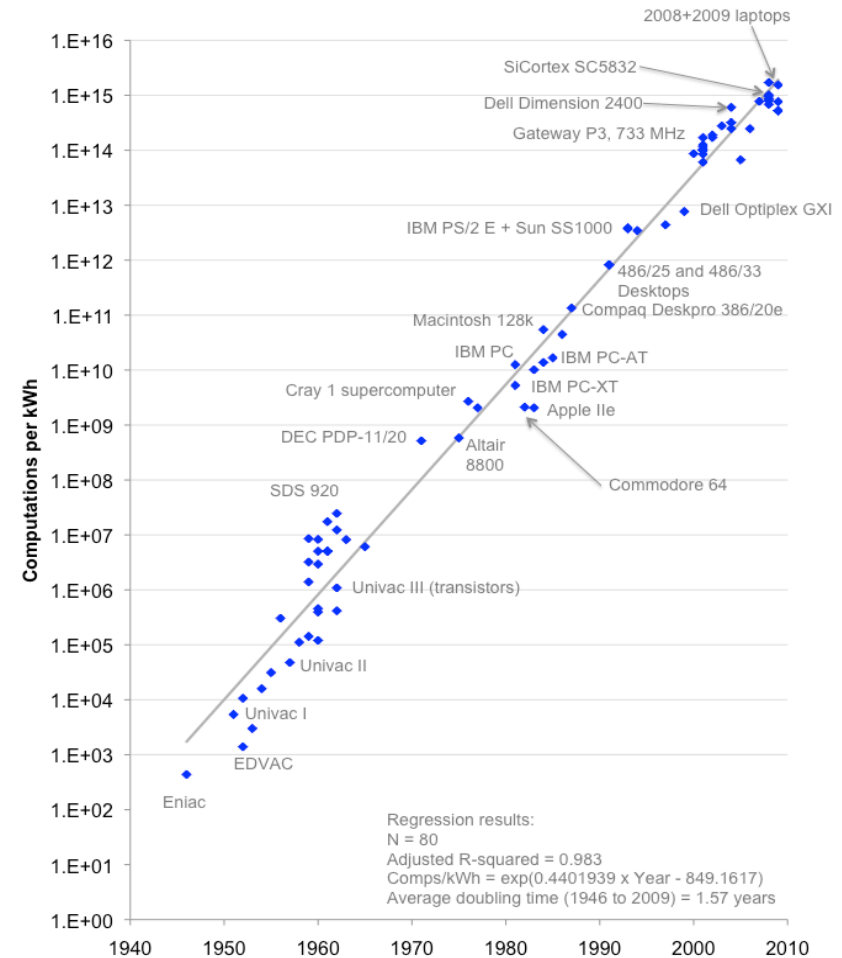
Source: Lower bound resource estimates from the IIASA Global Energy Assessment 2012 + calcs in *Cold Cash, Cool Climate* (fossil emissions only).

Lessons for entrepreneurs

- Start with tasks, then redefine them
- Focus on the whole system
- Time is money
- Modify property rights
- Harness information technology
 - Data collection
 - Substitute bits for atoms and smarts for parts
 - Transform institutions
- Work forward toward goals to learn more rapidly

Peak computing efficiency

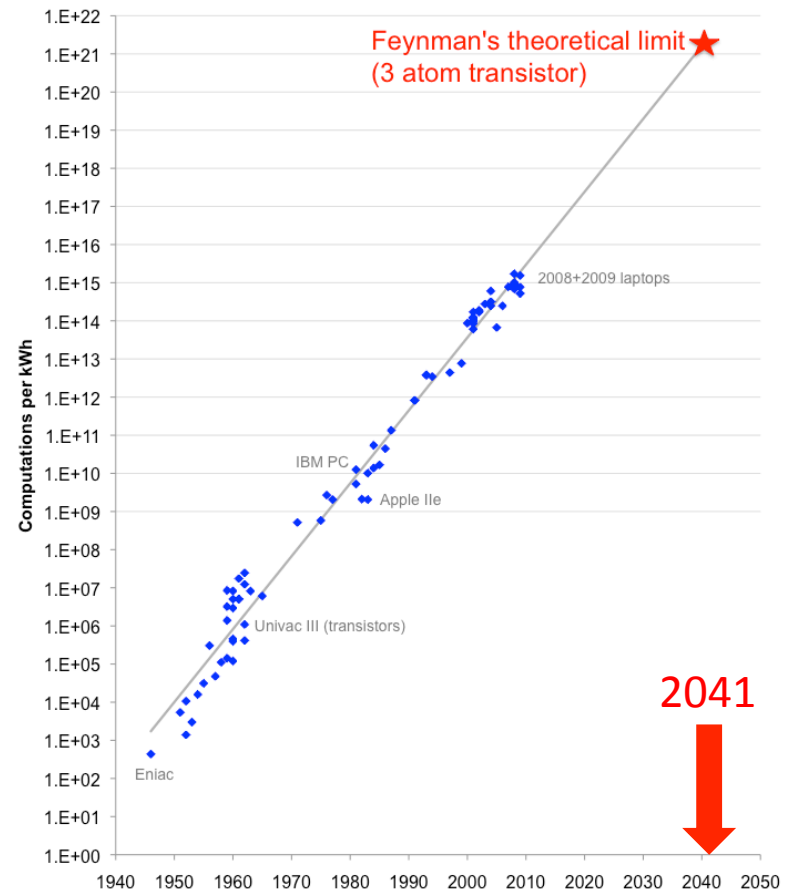
- Doubling about every year and a half since the 1940s
- 100x improvement every decade
- Enabled the existence of laptops and smart phones
- Trend slowing since 2000, but standby efficiency improving more rapidly since then



Source: Koomey et al. 2011

These trends still have a long way to run

Psssst: Researchers at
Purdue and the University of
New South Wales in 2012
created a reliable one atom
transistor...



Summary

- Warming limit approach is similar to how businesses make big strategic decisions
- Focus is on risk reduction, experimentation, evaluation, innovation and cost effectiveness, not on knowing “optimal” path in advance (impossible!)
- Science points to 2 deg C limit but ultimate choice is a political judgment
 - Declare value judgment up front (not buried in black box models, as is customary)
- Implies rapid reductions and keeping most fossil fuels in the ground (requires rapid innovations in technologies AND behavior/institutions)

Summary (continued)

- Immediate implementation is essential (can't just wait and see while doing R&D)
 - Learning by doing only happens if we *do*!
- Existing low carbon resources are plentiful but we'll need new innovations in later decades to keep reductions on track
- Start small. Think big. Get going!

“The best way to predict the future is to invent it.” –Alan Kay

References

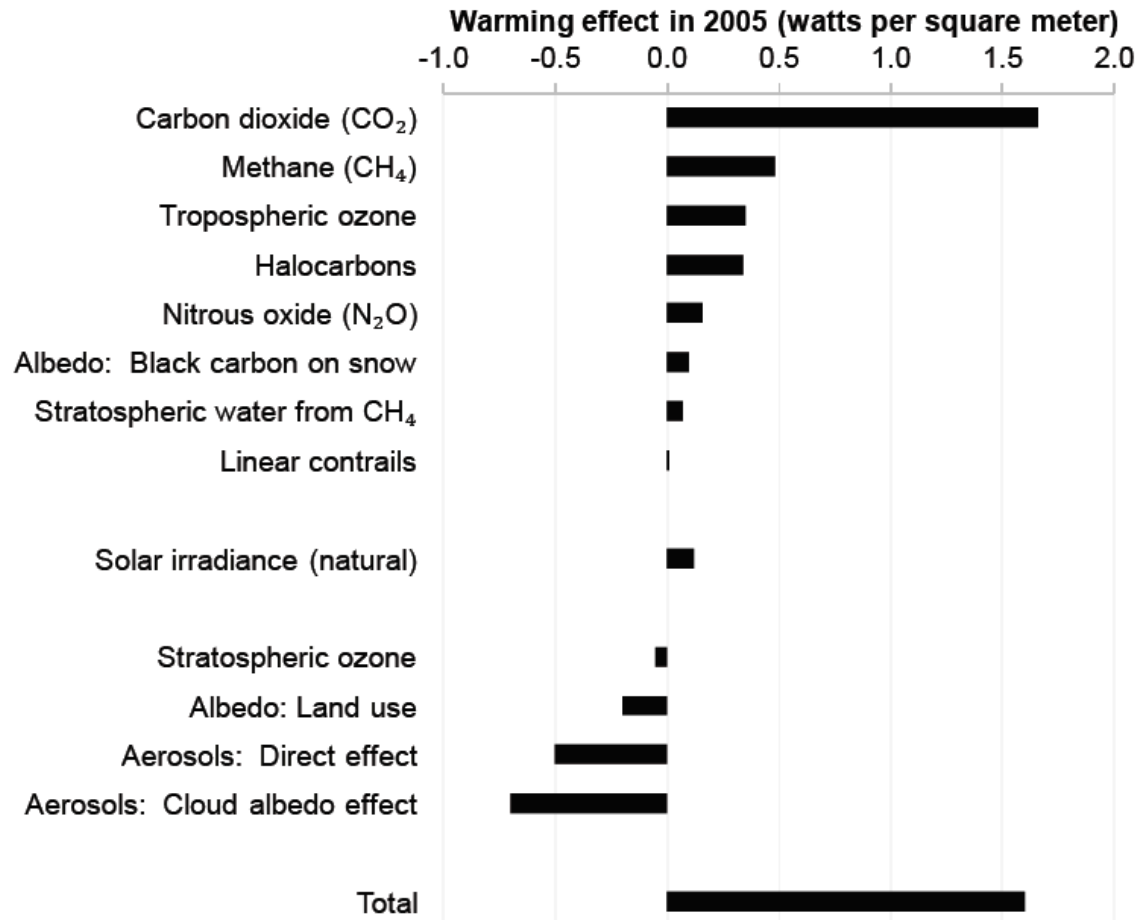
- Allison, et al. 2009. *The Copenhagen Diagnosis, 2009: Updating the World on the Latest Climate Science*. Sydney, Australia: The University of New South Wales Climate Change Research Centre (CCRC).
- Brynjolfsson, Erik, and Andrew McAfee. 2014. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York, NY: W. W. Norton & Company. [<http://amzn.to/1gYHEGk>]
- Caldeira, Ken, Atul K. Jain, and Martin I. Hoffert. 2003. "Climate Sensitivity Uncertainty and the Need for Energy Without CO₂ Emission " *Science*. vol. 299, no. 5615. pp. 2052-2054. <<http://www.sciencemag.org/cgi/content/abstract/299/5615/2052>>
- DeCanio, Stephen J. 2003. *Economic Models of Climate Change: A Critique*. Basingstoke, UK: Palgrave-Macmillan.
- Brown, Marilyn A., Mark D. Levine, Walter Short, and Jonathan G. Koomey. 2001. "Scenarios for a Clean Energy Future." *Energy Policy* (Also LBNL-48031). vol. 29, no. 14. November. pp. 1179-1196.
- Gritsevskiy, Andrii, and Nebojsa Nakicenovic. 2000. "Modeling uncertainty of induced technological change." *Energy Policy*. vol. 28, no. 13. November. pp. 907-921.
- Jones, P. D., D. E. Parker, T. J. Osborn, and K. R. Briffa. 2013. *Global and hemispheric temperature anomalies--land and marine instrumental records*. Oak Ridge, TN: CDIAC, Oak Ridge National Laboratory, U.S. Department of Energy. [<http://cdiac.esd.ornl.gov/trends/temp/jonescru/jones.html>]
- Koomey, Jonathan. Testimony of Jonathan Koomey, Ph.D. for a hearing on "Efficiency: The Hidden Secret to Solving Our Energy Crisis". Joint Economic Committee of the U.S. Congress. U.S. Congress. Washington, DC: U.S. Congress. July 30, 2008. <http://www.jec.senate.gov/index.cfm?FuseAction=Hearings.HearingsCalendar&ContentRecord_id=6fc51d63-e7e2-82b7-10c3-3faa2c150115>
- Koomey, Jonathan G., Stephen Berard, Marla Sanchez, and Henry Wong. 2011. "Implications of Historical Trends in The Electrical Efficiency of Computing." *IEEE Annals of the History of Computing*. vol. 33, no. 3. July-September. pp. 46-54. [<http://doi.ieeecomputersociety.org/10.1109/MAHC.2010.28>]
- Koomey, Jonathan G. *Cold Cash, Cool Climate: Science-Based Advice for Ecological Entrepreneurs*. Burlingame, CA: Analytics Press, 2012.
- Koomey, Jonathan. 2013. "Moving Beyond Benefit-Cost Analysis of Climate Change." *Environmental Research Letters*. vol. 8, no. 041005. December 2. [<http://iopscience.iop.org/1748-9326/8/4/041005/>]

References (continued)

- Krause, Florentin, Wilfred Bach, and Jonathan G. Koomey. 1992. *Energy Policy in the Greenhouse*. NY, NY: John Wiley and Sons. (1989 edition of this book downloadable at <<http://files.me.com/jgkoomey/9jzwgj>>)
- Luderer, Gunnar, Robert C. Pietzcker, Christoph Bertram, Elmar Kriegler, Malte Meinshausen, and Ottmar Edenhofer. 2013. "Economic mitigation challenges: how further delay closes the door for achieving climate targets." *Environmental Research Letters*. vol. 8, no. 3. September 17. [<http://iopscience.iop.org/1748-9326/8/3/034033/article>]
- Marcott, Shaun A., Jeremy D. Shakun, Peter U. Clark, and Alan C. Mix. 2013. "A Reconstruction of Regional and Global Temperature for the Past 11,300 Years." *Science*. vol. 339, no. 6124. March 8, 2013. pp. 1198-1201. [<http://www.sciencemag.org/content/339/6124/1198.abstract>]
- Meinshausen, Malte, Nicolai Meinshausen, William Hare, Sarah C. B. Raper, Katja Frieler, Reto Knutti, David J. Frame, and Myles R. Allen. 2009. "Greenhouse-gas emission targets for limiting global warming to 2 degrees C." *Nature*. vol. 458, April 30. pp. 1158-1162. <<http://www.nature.com/nature/journal/v458/n7242/full/nature08017.html>>
- Pacala, S., and Rob Socolow. 2004. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies" *Science*. vol. 305, no. 5686. August 13. pp. 968-972. [<http://www.sciencemag.org/cgi/content/abstract/305/5686/968>]
- Joeri, Rogelj, Meinshausen Malte, Sedláček Jan, and Knutti Reto. 2014. "Implications of potentially lower climate sensitivity on climate projections and policy." *Environmental Research Letters*. vol. 9, no. 3. pp. 031003. [<http://stacks.iop.org/1748-9326/9/i=3/a=031003>]
- Williams, James H., Andrew DeBenedictis, Rebecca Ghanadan, Amber Mahone, Jack Moore, William R. Morrow, Sneller Price, and Margaret S. Torn. 2011. "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity." *Science*. November 24. [<http://www.sciencemag.org/content/early/2011/11/22/science.1208365.abstract>]

Extra slides

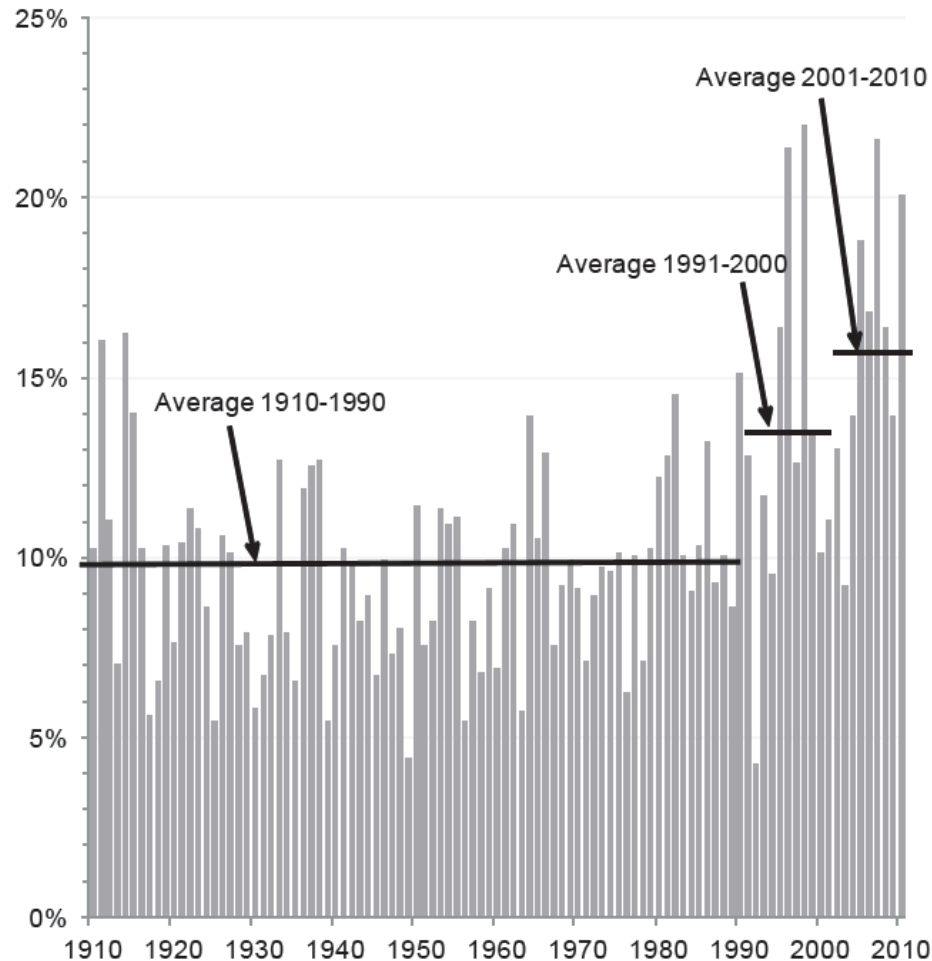
Contributors to climate change through 2005



Source: IPCC 2007 (Working Group 1, the Physical Science Basis)

Copyright Jonathan Köpcke 2014

Percent of US land area subject to 1 day precipitation extremes



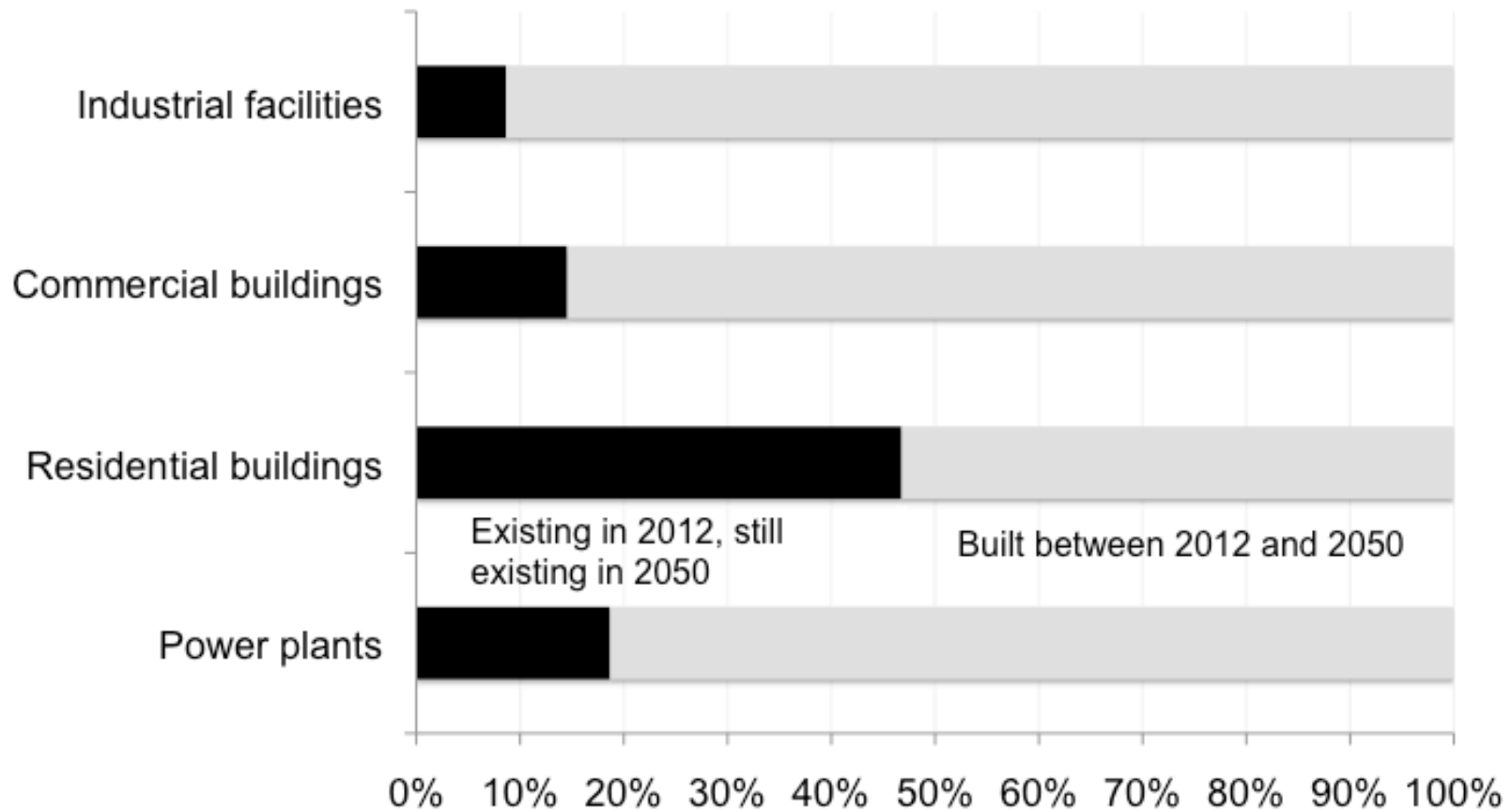
Source: NCDC/NOAA 2011

Copyright Jonathan Koomey 2014

2 C degree warming limit

- Keeps global T within humanity's experience
- Likely avoids the worst of the positive feedbacks
- Implies cumulative GHG emissions “budget”
- Limit itself now widely accepted (e.g., G8 in 2009), but implications still not well known
 - Global emissions must turn down this decade, down 50% by 2050, more soon afterwards
 - Waiting has a real cost
 - We must act quickly on many fronts
 - It's Sputnik, not Apollo
 - We can't burn it all
 - C Storage not practically relevant for decades, if ever

Most 2050 infrastructure built between now and 2050



Forecasts often underestimate the possibilities for change

- Economic models (with very few exceptions)
 - assume current rigidities will continue forward in the forecast (“The Big Mistake”, related to Ascher’s “assumption drag”)
 - assume structure of property rights is constant
 - ignore increasing returns to scale
 - rely on incomplete technology and policy portfolios
 - ignore “no-regrets” options
- All but last issue true for top-down AND bottom-up models

Delaying makes no sense in the warming limit context

- *When* we act makes a difference
- Delaying action on climate
 - eats up the budget
 - makes required reductions more difficult and costly later
 - sacrifices learning and reduces possibilities for future action
- Remember, energy techs don't Δ fast

Impacts of Uncertainty, Learning, and Spillovers (IPCC AR4 , 2007)

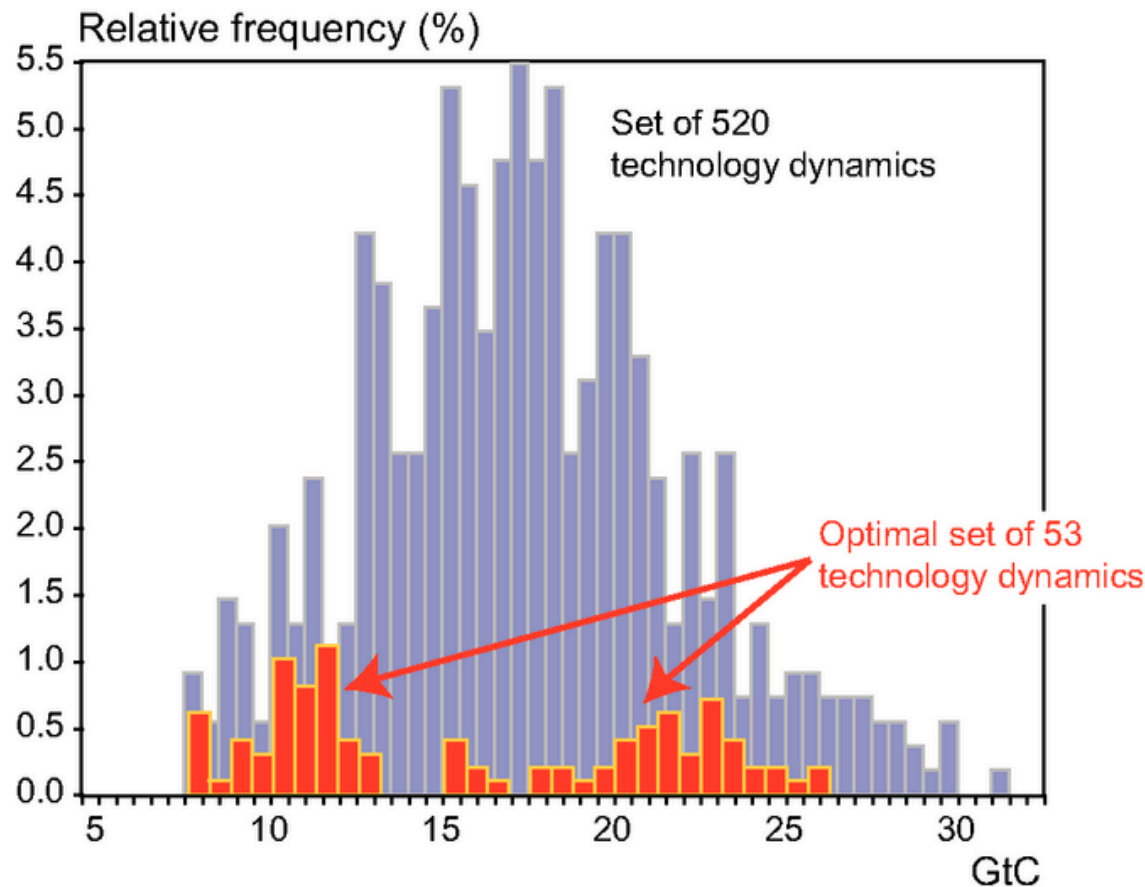


Figure 2.2. Emissions impacts of exploring the full spectrum of technological uncertainty in a given scenario without climate policies. Relative frequency (percent) of 130,000 scenarios of full technological uncertainty regrouped into 520 sets of technology dynamics with their corresponding carbon emissions (GtC) by 2100 obtained through numerical model simulations for a given scenario of intermediary population, economic output, and energy demand growth. Also shown is a subset of 13,000 scenarios grouped into 53 sets of technology dynamics that are all "optimal" in the sense of satisfying a cost minimization criterion in the objective function. The corresponding distribution function is bi-modal, illustrating "technological lock-in" into low or high emissions futures respectively that arise from technological interdependence and spillover effects. Baseline emissions are an important determinant for the feasibility and costs of achieving particular climate targets that are *ceteris paribus* cheaper with lower baseline emissions. Adapted from Gritsevskyi and Nakicenovic, 2000.

Decanio concludes...

“The application of general equilibrium analysis to climate policy has produced a kind of specious precision, a situation in which the assumptions of the analysts masquerade as results that are solidly grounded in theory and the data. This leads to a tremendous amount of confusion and mischief, not least of which is the notion that although the physical science of the climate is plagued by uncertainties, it is possible to know with a high degree of certainty just what the *economic* consequences of alternative policy actions will be.” (italics in original)

Fossil fuel resources are huge

TABLE A-1: Lower bound estimates of energy and carbon content of fossil fuels worldwide

	Energy content (ZJ)				Carbon content (GtC)			
	Reserves	Resources	Resource base	Notes	Reserves	Resources	Resource base	Notes
Conventional fuels								
Natural gas	5	7	12	1	77	110	187	5
Oil	5	4	9	1	98	83	181	5
Coal	17	291	308	1	446	7508	7954	5
Total conventional	27	302	330		621	7701	8322	
Unconventional fuels								
Coalbed methane	3	6	9	2	47	93	139	5
Shale gas	5	10	14	2	72	148	220	5
Deep gas	3	5	8	2	47	80	127	5
Tight gas	4	5	10	2	66	80	146	5
Oil sands	1	4	5	3	29	78	106	5
Heavy oil	6	1	7	3	123	26	149	5
Shale oil	1	2	3	3	22	43	66	5
Total unconventional	24	34	57		405	548	953	
Exotic								
Methane hydrates			65	4			1000	6
Total, conv. + unconv.	51	336	387		1026	8249	9275	

Note: Current annual global primary energy use is 0.6 ZJ (1 ZJ = 1000 EJ or 10e21 J), which is about 30 TW.